CERTIFICATE OF TRANSLATION

As a below named translator, I hereby declare that my residence and citizenship are as stated below next to my name and I hereby certify that I am conversant with both the English and Korean languages and the document enclosed herewith is a true English translation of the Invention Disclosure with respect to the Korean patent application No. 1999-26862 filed on July 5, 1999.

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Date : September 21, 2006

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CITIZENSHIP : REPUBLIC OF KOREA

Dept.	Proposal	Judge.	Determin.	Employee Invention Report I assign the right to get the patent for the invention under Article 4 & Articles of Chapter 2 of the employee invention repayment rule of our company based on Paragraph 1 of Article 40 of the Patent Law (made on October 20, 1998)	Patent Manag. Dept.	Proposal	Exam.	Determin..
	Signed	Signed	Signed			Signed	Signed	

TITLE	CARRIER RECOVERY IN OFDM-CDMA SYSTEM USING GUARD INTERVAL AND PILOT SYMBOL
Gist of the invention	A transmitter of an OFDM-CDMA system properly inserts a pilot symbol among data symbols, and a receiver can effectively find a frequency offset by using the pilot symbol and a guard interval regardless of noise, channels, timing errors, CPE, etc.
Key word	OFDM-CDMA system, frequency error, frequency offset, carrier recovery, pilot symbol, reference phase, guard interval

Product Name		Subject		Subject Code	7040

Inventor Name (Chinese) Inventor Name (English)	Station	Registered Residence Address & Postal Code	Residence Code Employee Code (salary step)	Internal phone No.
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To be filled by Patent Manag. Dept.						
	Result of Determination	√Typical, Domestic priority, Combined, Divisional, Reapplication, Returned	Right	■ Patent ☐ Utility Model		
	Urgency	■3 ☐2 ☐1	Invention Grade	☐A ■B ☐C	Examination	■ requested ☐ no
	Abroad	☐ N ■ Y				
	Opinion	GC-9810-004 GC-9810-005	Product Code Tech. Class	CBDG, EBAOA ■Circuit☐Machinery ■Method ☐ Process ☐ others ( )		
	Receipt No.	GC-9810-036	Confirmation	Agent	Lee Gun Ju Patent Office	
	Receipt Date	[redacted]			Receipt No.: · (19 . .)	
	Determination Date	[redacted]			In charge by: Sang chol, Nam ( )	
	Delegated Date	[redacted]			Others:	
	Inspector	Sang hwan, Park				

EVALUATION TABLE

Class	Evaluation Item / Point	Weight	Rating Standard					Rating by Manager (General Manager)	Rating By Officer (General Manager)	Intellectual Property Team
Patentability	Construction of Invention	15	13~15	10~12	7~9	4~6	1~3			
	Means for solving problems has novelty ? (as compared with the prior art)		New basic invention	Important technology with high difficulty	Important technology with normal difficulty	Partial improvement with low difficulty	Method change without effect			
	Effect of Invention	20	17~20	13~16	9~12	5~8	1~4			
	Expected effect by the novel construction (improvement, shrink, process reduction, yield improvement, cost down, etc.)?		Extremely dominant	Very dominant	Dominant	Common	Poor			
Exclusiveness	Existence of alternative technology	10	9~10	7~8	5~6	3~4	1~2			
	Alternative technology/avoiding technology is possible? And superiority when possible?		Replacement/avoidance impossible	Possible but the invention is extremely good	Possible but the invention is very good	Possible but the invention is good	Possible with no difference			
	Usability by other companies	10	9~10	7~8	5~6	3~4	1~2			
	Usable/operable by other companies?			High possibility	Middle possibility	Low possibility	No possibility			
Infringement	Detection of Infringement	10	9~10	7~8	5~6	3~4	1~2			
	Easily detectable when infringed by others?		Extremely easy	Very easy	Common	Difficult	Possible when inspected in spot			
Economic Value	Operability	20	17~20	13~16	9~12	5~8	1~4			
	Surrounding conditions for operation of the invention has been prepared? Is there any technological difficulty?		Instantly operable without modification	Instantly operable with modification	Operation expected	Defensive Application	IDEA Invention			
	Application Range	15	13~15	10~12	7~9	4~6	1~3			
	Application range applied to the product or technology?		Very wide	Wide	Common	Rather narrow	Very narrow			
		100			Score		Total score			

	Current Development Stage	☐Idea ☐Subject for future development ☐Plan ☐PROTO ☐ EVT ☐DVT ☐MVT ☐Others ( )		■Internal invention ☐ Cooperation with Academy ☐Purchased patent ☐Branch Legal person ☐Ordered Development ☐ Transferred business ☐Research center case ☐ Cooperative Company case ☐ Others
	Application to product	☐Being applied ☐Expected ( ) ☐unscheduled		
	Application Type	☐Domestic ☐ Abroad (Countries:)		

<table>
<tr><td rowspan="2"></td><td>☐ Published (   )
☐ To be published (   )
☐ No publication
* Countries when published (   )</td><td>☐Newspaper ☐ Exhibition
☐Publication ☐ Catalog
☐Institute ☐ Order
* to be accompanied by related documents</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td colspan="2">[Dept. Chief Opinion]

patent relating to searching of base station power in handoff in CDMA

Stamp</td></tr>
</table>

Employee Invention Report (Invention Disclosure) ● Title of Invention		[Points to be pre-checked] ○ prompt application is necessary under the first-to-file system ○ complete invention is necessary - the invention must be backed up by embodiments, data, etc. - incomplete or only desired idea is not available ○ publication before application is prohibited - academy presentation, paper publication, sale, display, etc. are prohibited
Korean	Guard interval 과 파일럿 심볼을 이용한 OFDM-CDMA system 에서의 주파수 오류 복구 방법	
English	Carrier Recovery In OFDM-CDMA system using guard interval and pilot symbol	

1. Background of invention	- all technologies in relation to the present invention, which have already been filed or are currently pending - improvement application can be filed within one year from the first application data, with domestic priority claiming

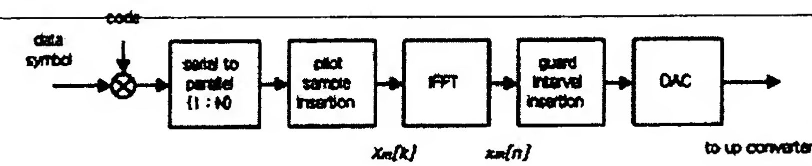
[Technology Source] (optionally fill only corresponding blanks)	Similar patent or application	Application/registration No.			Application/registration Date	
		Title of Invention				
		Applicant				
	Background document or product	Document name/product model name			Publisher/manufacturer	
		Publication/production date			Page/others	
	Prior application(s) of the inventor(s) related to the invention	Filed application(s)	Title of invention			
			Application no./date	(19 ...)		
		Pending application(s)	Title of invention			
			Receipt no./date	(19 ...)		

A. FIELD OF INVENTION

The present invention relates to a method for estimating and compensating for a frequency offset in a receiver of an OFDM system or an OFDM-CDMA system.

B. DRAWING OF PRIOR ART

(a). Transmitter



(B). Receiver

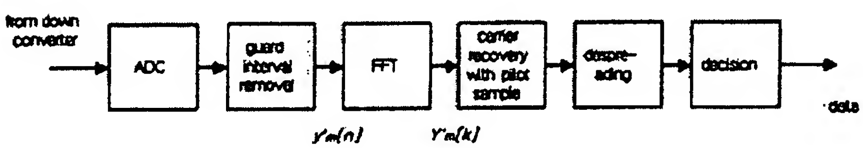


FIG. 1 illustrates transmitter/receiver of an OFDM-CDMA system using a pilot sample

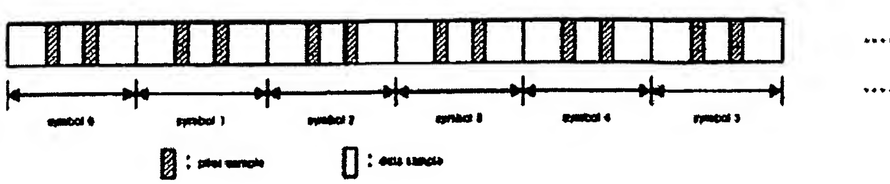


FIG. 2 illustrates a data structure in an existing method using a pilot sample

C. DESCRIPTION AND PROBLEMS OF PRIOR ART

FIG. 1 illustrates the basic transmitter/receiver of an OFDM-CDMA system. First, the transmitter spreads a data symbol to be transmitted by multiplying the data symbol by a code of an N rate, performs an Inverse Fast Fourier Transform (IFFT) for the data by the symbol, i.e. by the N samples, inserts a guard interval with a length of a G sample into the IFFTed data, and transmits the IFFTed data. The receiver detects the start point of a symbol from the received data, removes the guard interval, and performs FFT and dispreading for the data so as to obtain the original transmission data.

Herein, a baseband signal includes a frequency offset due to the inaccuracy of an oscillator used in the down converter of the receiver. Then, if the signal is subjected to a FFT, a signal shifted by the frequency offset is obtained. Therefore, it is nearly difficult to recover the original data. Specifically, in an OFDM-CDMA system where a desired signal is carried at each frequency band, the frequency offset should be correctly estimated and compensated for to recover the original signal. The OFDM-CDMA system generally recovers the frequency offset by using the FFT characteristics shown in an equation below.

$$X[n]W_N^{K_0 n} \leftrightarrow X[k-k_0] \quad where\ W_e = e^{\frac{-j2\pi}{N}}$$

In order to use the characteristics, in the OFDM system, the transmitter inserts a predetermined number of pilot samples into preset positions of a data symbol as illustrated in FIG. 2, and the receiver estimates the frequency offset by calculating the shift amount of the data.

In an ideal system, since the pilot samples received as shown in the equation above are received in a position shifted by k_0 samples from the original reference sample position, it is possible to calculate the frequency offset k_0 by estimating the shifted value by means of a correlator. However, when the pilot samples are used in the OFDM-CDMA system, performance deterioration may occur, e.g. a data rate may increase more than twice, a receiver may become complicated, or a noise level may increase. On account of this, it is difficult to use the method utilizing the pilot samples.

A non-ideal system has more serious problems. Factors affecting the IFFTed signal include a timing error, a Common Phase Error (CPE), noise, etc.

In the receiver, after passing through the FFT stage, a timing error n_e in a time domain is expressed by the product of the original signal in a frequency domain and an exponential term. This ultimately has influence on the value of the pilot sample. Accordingly, if this value increases, it may considerably deteriorate the performance of the correlator. As a result, it is difficult to detect a correct frequency offset value by using the above-described method.

D. SOLUTION OF PROBLEMS OF THE PRIOR ART & OBJECTS OF THE INVENTION

The object of the present invention is to provide a method for estimating and compensating for a coarse frequency offset by using a guard interval in an OFDM-CDMA system, and estimating and compensating for a fine frequency offset by using pilot samples inserted at regular intervals. Specifically, the object of the present invention is to estimate a frequency offset without performance deterioration even when a timing error has occurred, and to easily estimate the frequency offset by removing the influence due to noise.

2. DRAWING OF THE INVENTION

FIG. 3 illustrates a data structure in a proposed method using a pilot symbol

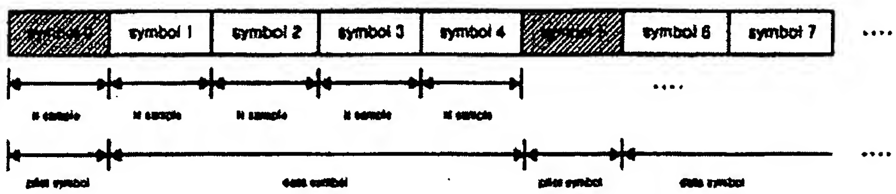
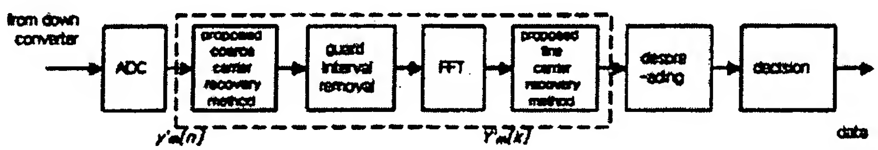


FIG. 4 is a block diagram of a receiver using a proposed carrier recovery method



3. DETAILED DESCRIPTION OF THE INVENTION

A. CONSTRUCTION OF THE INVENTION

B. OPERATION OF THE INVENTION

The present invention proposes a method in which a transmitter prepares guard intervals and inserts pilot symbols among data symbols at regular intervals as illustrated in FIG. 3, and a receiver uses information about the insertion, in order to estimate a frequency offset under the real conditions including a timing error, a CPE, noise, etc.

First, an OFDM-CDMA system must model a signal actually received under the real conditions including a frequency offset, a CPE, noise, a timing error, etc. As illustrated in FIG. 1, if a signal of an IFFT input unit is $X_m(k)$ and a signal before a guard interval is inserted after passing through the IFFT unit is $X_m(n)$ in the transmitter of the OFDM-CDMA system, a signal $y'_m(n)$ after

passing through a down converter and an ADC, and a signal $y'_m(k)$ after removing the guard interval and passing through a FFT unit in the receiver may be modeled as follows.

If a frequency offset per symbol is k_e [Hz/symbol], a frequency offset per sample is k_e/N [Hz/sample], and a frequency offset $k_m[n]$ of an n^{th} sample in an m^{th} symbol is expressed by an equation below.

$$k_m[n] = \frac{k_e}{N} m\{N + G\} + \frac{k_e}{N} n$$

In the receiver, signal $y_m(n)$ including the frequency offset, the CPE, the noise, etc., may be modeled by an equation below, in which, for convenience, a sample number is given from –G to N-1. A guard interval denotes intervals of predetermined length among symbols prepared in order to remove interference among the symbols of OFDM signals. A method for copying the last G samples of each symbol and inserting the copied samples before each symbol has been most generally used.

$$\begin{aligned}
y_m[n] &= X_m[n] \cdot e^{j2\pi k_m[n]} \cdot e^{jP_e} + W_m[n] \\
&= X_m[n] \cdot e^{\frac{j2\pi k_e[m(N+G)+n]}{N}} \cdot e^{jP_e} + W_m[n] \\
&= X_m[n] \cdot e^{j2\pi k_e \frac{n}{N}} \cdot e^{\frac{j2\pi k_e m(N+G)}{N}} \cdot e^{jP_e} + W_m[n]
\end{aligned}$$

$$\begin{aligned}
&\textit{where } n = -G, -G+1, \ldots, 0, 1, \ldots, N-1 : \textit{sample number} \\
&\quad m = 0,1,2\ldots : \textit{symbol number} \\
&\quad N : \textit{no. of samples / 1 symbol} \\
&\quad G : \textit{no. of samples of guard interval} \\
&\quad k_m[n] : \textit{frequency offset of } n^{th} \textit{ sample in } m^{th} \textit{ symbol} \\
&\quad P_e : \textit{Common Phase Error} \\
&\quad W_m[n] : \textit{AWGN of } m^{th} \textit{ symbol}
\end{aligned}$$

If there is no timing error, it is possible to estimate a coarse frequency

offset by using G samples corresponding to a guard interval in the received signals, the guard interval, and the last G samples in a symbol in which the same data has been transmitted. The signal of the guard interval, i.e. the first G samples $G_m(n)$ in a m^{th} symbol and the last G samples $R_m(n)$ in the symbol may be expressed by an equation below.

$$
\begin{aligned}
G_m[n] &= y_m[n-G] \\
&= x_m[n-G]\cdot e^{\frac{j2\pi k_e[n-G]}{N}}\cdot e^{\frac{j2\pi k_e m[n+G]}{N}}\cdot e^{jP_e}+W_m[n-G] \\
&\text{where } n=0,1,\ldots,G-1 \\
R_m[n] &= y_m[n+N-G] \\
&= x_m[n+N-G]\cdot e^{\frac{j2\pi k_e[n+N-G]}{N}}\cdot e^{\frac{j2\pi k_e m[N+G]}{N}}\cdot e^{jP_e}+W_m[n+N-G] \\
&\text{where } n=0,1,\ldots,G-1
\end{aligned}
$$

The phases of $G_m(n)$ and $R_m(n)$ and phase difference of $G_m(n)$ and $R_m(n)$ may be expressed by an equation below.

$$
\begin{aligned}
&\angle G_m[n]=\angle x_m[n-G]+\frac{2\pi k_e[n-G]}{N}+\frac{2\pi k_e m[n+G]}{N}+P_e+\angle W_m[n-G] \\
&\text{where } n=0,1,\ldots,G-1 \\
&\angle R_m[n]=\angle x_m[n+N-G]+\frac{2\pi k_e[n+N-G]}{N}+\frac{2\pi k_e m[n+G]}{N}+P_e+\angle W_m[n+N-G] \\
&\text{where } n=0,1,\ldots,G-1 \\
&\angle R_m[n]-\angle G_m[n] \\
&=\angle x_m[n+N-G]-\angle x_m[n-G]+\frac{2\pi k_e[n+N-G]}{N}-\frac{2\pi k_e m[n-G]}{N}+\angle W_m[n+N-G]-\angle W_m[n-G] \\
&=2\pi k_e+\angle W_m[n+N-G]-\angle W_m[n-G] \\
&\text{where } n=0,1,\ldots,G-1
\end{aligned}
$$

In the above equation, since $x_m[n+N-G]$ and $x_m[n-G]$ are the identical signals, the phase difference is zero. If an average value of G phase differences is computed in order to remove the influence due to noise, the following equation may be obtained.

$$k_e = \frac{avg\{\angle R_m[n] - \angle G_m[n]\}}{2}$$
$$where\ n = 0,1,\ldots,G-1$$

If a timing error exists, cases may occur, in which the above equations are not established. If the timing error, such as an FFT start point detection error, a timing frequency offset and a timing phase offset, is n_e, a signal $y'_m[n]$ including the timing error may be modeled by an equation below.

$$y'_m[n] = y_m[n-n_e] = x_m[n-n_e]\cdot e^{\frac{j2\pi k_e[n-n_e]}{N}}\cdot e^{\frac{j2\pi k_e m[n+G]}{N}}\cdot e^{jP_e} + W_m[n-n_e]$$

Herein, $y'_m[n]$ includes samples of a $(m-1)^{th}$ symbol or a $(m+1)^{th}$ symbol according to the value of n_e. In this signal, when the first G samples of a symbol are $G_m[n]$ and the last G samples of a symbol are $R_m[n]$ in this way, the phase difference of each sample is computed by an equation below.

$$\begin{aligned}
&\angle R_m[n] - \angle G_m[n] \\
&= \angle x_m[n+N-G-n_e] - \angle x_m[n-G-n_e] \\
&+ \frac{2\pi k_e[n+N-G-n_e]}{N} - \frac{2\pi k_e[n-G-n_e]}{N} + \angle W_m[n+N-G-n_e] - \angle W_m[n-G-n_e] \\
&= \angle x_m[n+N-G-n_e] - \angle x_m[n-G-n_e] + 2\pi k_e + \angle W_m[n+N-G-n_e] - \angle W_m[n-G-n_e] \\
&where\ n = 0,1,\ldots,G-1
\end{aligned}$$

In the above equation, $G_m[n]$ and $R_m[n]$ have the values shifted by n_e from their original values, so that $X_m[n+N+G-n_e]$ and $X_m[n-G-n_e]$ have the same range $n=n_e, n_e+1, .., G-1$ when n_e has a positive number and $n=0, 1, 2, .., G-n_e-1$ when n_e has a negative number. Hence, if an approximate range of the timing error of the system is known, the frequency offset is computed in intervals from which the ranges are excluded. For example, if a maximum timing error does not exceed 'a', the frequency offset can be estimated using an equation below by

computing both the phase difference in the interval of n=a, a+1, .., G-a-2, G-a-1, and the average value.

$$k_e = \frac{avg\{\angle R_m[n] - \angle G_m[n]\}}{2}$$
$$where\ n = a, a+1, \ldots, G-a-2, G-a-1$$

This method shows good performance as the guard interval has a long length and the timing error of the system has a narrow range. Otherwise, since a frequency offset measurement interval becomes shorter, the method is affected by noise and cannot accurately estimate a frequency offset. However, the estimation of a coarse frequency offset is possible. Accordingly, after compensating for the frequency offset by using the method, a remaining fine frequency offset can be estimated using the phase difference of two consecutive pilot symbols.

In the receiver, if the signal removing the guard interval passes through the FFT unit, a frequency offset according to the FFT characteristics is a shift timing error of the signal and is converted to a variation of the phase. This can be expressed by an equation below. Herein, k_i denotes the fine frequency offset.

$$\begin{aligned} y'_m[k] &= x_m[k-k_i] \cdot e^{\frac{j2\pi[k-k_i]n_e}{N}} \cdot e^{\frac{j2\pi k_i m[N+G]}{N}} \cdot e^{jP_e} + W_m[k-k_i] \\ &= x_m[k-k_i] \cdot e^{\frac{j2\pi k n_e}{N}} \cdot e^{-\frac{j2\pi k_i n_e}{N}} \cdot e^{\frac{j2\pi k_i m[N+G]}{N}} \cdot e^{jP_e} + W_m[k-k_i] \end{aligned}$$

Only the pilot symbol can be detected from the received signal as follows.

$$y'_m[k] = x_m[k-k_i]\cdot e^{\frac{j2\pi kn_\varepsilon}{N}}\cdot e^{-\frac{j2\pi k_i n_\varepsilon}{N}}\cdot e^{\frac{j2\pi k_i m[N+G]}{N}}\cdot e^{jP_e} + W_m[k-k_i]$$

$$\begin{aligned} where\ m &= 0, l-1, 2l-1, 3l-1, \ldots\ldots \\ &= m_{p0}, m_{p1}, m_{p2}, m_{p3}, \ldots\ldots \end{aligned}$$

l denotes a period of inserting the pilot symbol of the symbol unit

The phase of the received pilot symbol is computed by an equation below.

$$\angle y'_m[k] = \angle x_m[k-k_l] + \frac{2\pi n_e}{N}k - \frac{2\pi n_e k_i}{N} + \frac{2\pi k_i m[N+G]}{N} + P_e + \angle W_m[k-k_l]$$

$$where\ m = m_{p0}, m_{p1}, m_{p2}, m_{p3}, \ldots\ldots$$

Wherein, the second term is expressed in terms of a specific variation of the phase according to an index k, the next three terms are expressed in terms of a constant phase offset, and the last term is expressed in terms of fluctuation of the phase. If the transmitter continues to use the same pilot symbol, and the time error, the CPE and the frequency offset are identical during the pilot symbol insertion period, then a phase difference between two consecutive pilot symbols $Y_{mpi}'(k)$ and $Y_{mp(i+1)}$ (k) may be computed as follows.

$$\begin{aligned} diff_{phase} &= \angle y'_{m_{pl+1}}[k] - \angle y'_{m_{pl}}[k] \\ &= \angle x_{m_{pl+1}}[k-k_l] - \angle x_{m_{pl}}[k-k_l] + \frac{2\pi k_i m_{pl+1}[N+G]}{N} - \frac{2\pi k_i m_{pl}[N+G]}{N} + \angle W_{m_{pl+1}}[k-k_l] - \angle W_{m_{pl}}[k-k_l] \end{aligned}$$

If the transmitter uses the same pilot symbol as described above, the first term and the second term have the same value. Hence, the above equation may be expressed by an equation below.

$$\begin{aligned} diff_{phase} &= [m_{pl+1} - m_{pl}]\frac{2\pi k_i[N+G]}{N} + \angle W_{m_{pl+1}}[k-k_i] - \angle W_{m_{pl}}[k-k_l] \\ &= l\frac{2\pi k_i[N+G]}{N} + \angle W_{m_{pl+1}}[k-k_l] - \angle W_{m_{pl}}[k-k_l] \end{aligned}$$

Wherein, the first term is expressed in terms of a constant for N samples

of one pilot symbol, and the other terms are expressed in terms of fluctuation due to noise. Hence, an average value of the phase differences for N samples is computed, so that it is possible to obtain the constant of the first term, from which the influence of the noise is almost removed. From this value, it is possible to compute a frequency offset k_e as expressed by an equation below.

$$k_e = \frac{avgdiff_{phase} * N}{2\pi[N+G]*l}$$

C. EFFECTS OF THE INVENTION

According to the method proposed by the present invention, frequency offset compensation is possible even in a state where a timing error has not been compensated for, differently from existing methods. Further, it is possible to increase the accuracy of frequency offset estimation by removing the influence of fluctuation due to noise.

4. CLAIMS

1. A method for estimating and compensating for a coarse frequency offset by using a guard interval and compensating for a fine frequency offset by using two consecutive pilot symbols.

1-1. The method for estimating the coarse frequency offset by using phase difference between a sample of the guard interval and equal samples within a symbol.

1-2. The method for restricting an interval in order to remove influence due to a timing error and noise, and averaging the phase difference.

1-3. The method for using an equal symbol in all pilot symbols.

1-4. The method for averaging phase difference of each sample in two consecutive pilot symbols so as to remove influence due to noise.

1-5. The method for computing the frequency offset by using the computed average value.